

# CHARACTERIZATION OF THE BIOMECHANICAL BEHAVIOR OF THE OPTIC NERVE SHEATH

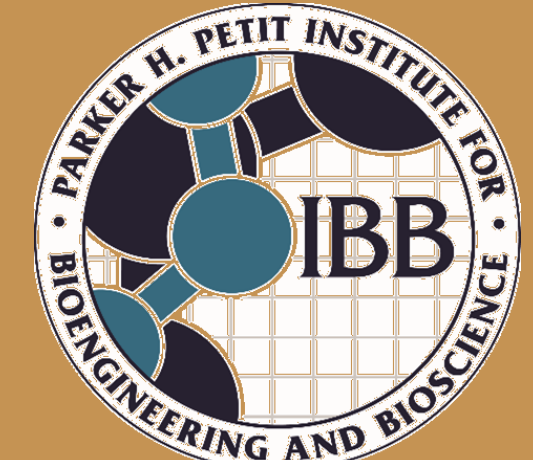


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## BACKGROUND – VIIP Syndrome

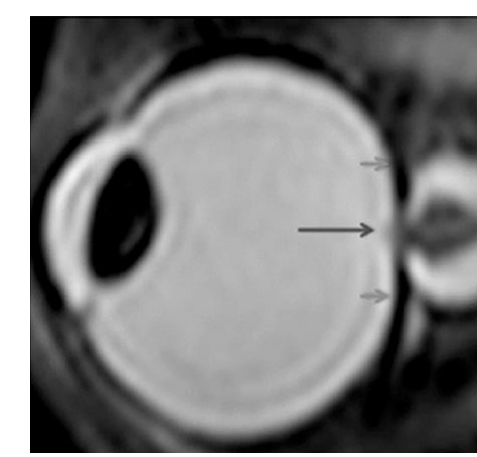
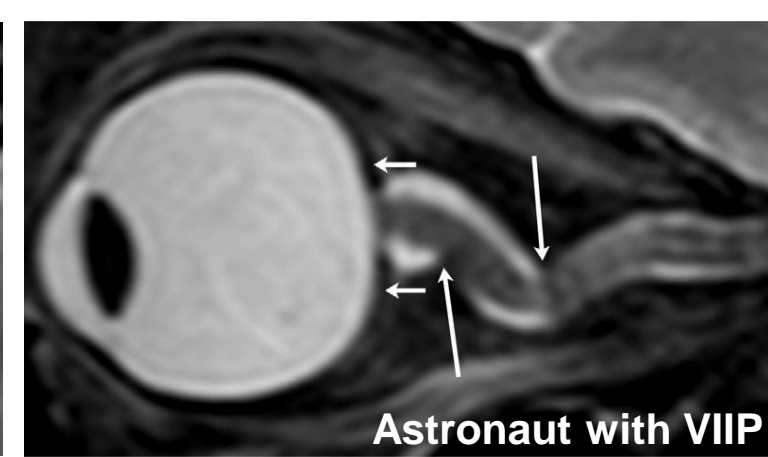
Visual Impairment and Intracranial Pressure (VIIP) syndrome is a constellation of ophthalmic changes that occurs in astronauts following long-duration spaceflight. Understanding the mechanisms that lead to the ocular changes involved in VIIP is of critical importance for space medicine research.

**Cephalad fluid shift hypothesis:** In microgravity, the pressure gradient in the body is significantly reduced, resulting in higher pressures in the head, producing increased Intracranial Pressures (ICP)

Some astronauts present with optic nerve distension and/or a kink in the optic nerve after return to Earth, strongly suggesting that axial distension and tissue remodeling in response to ICP increases may be taking place.

Optic nerve kinking

Optic nerve distension



Kramer et al. Radiology, 2012.

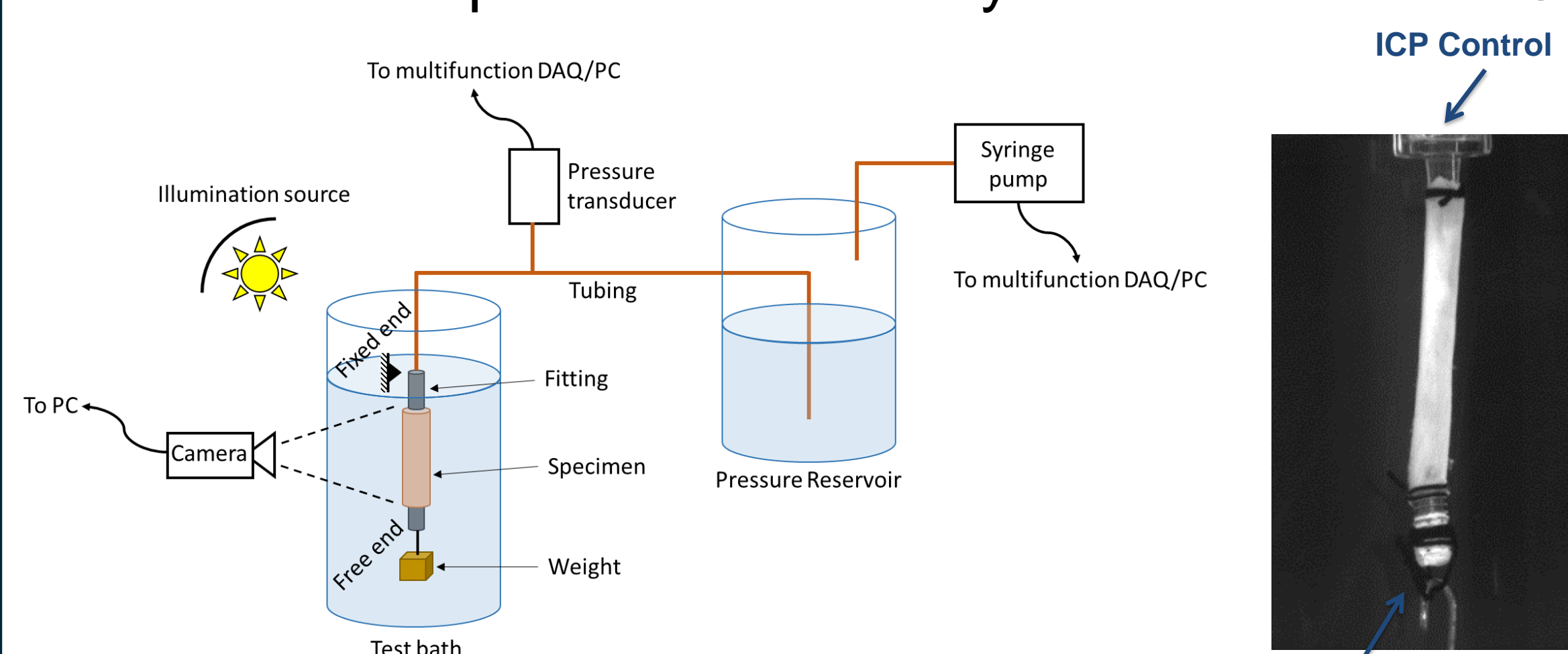
Mader et al. Ophthalmology, 2011

The goal of this work is to characterize the mechanical properties of the optic nerve sheath to better understand its biomechanical response to increased ICP.

## METHODS



- Fresh porcine eyes obtained from a local abattoir
- The optic nerve sheath (ONS) was isolated from the optic nerve proper, then cut away from the globe and attached to a pressure control system to simulate ICP



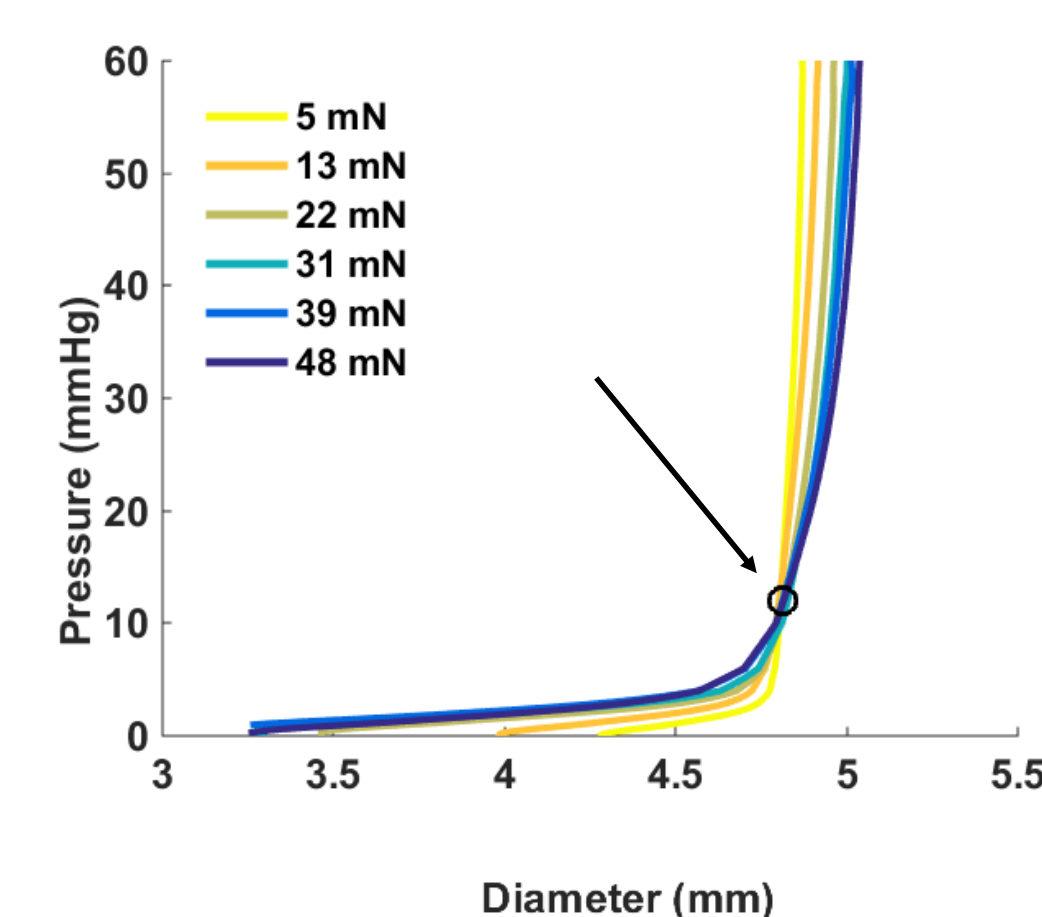
Schematic of the experimental setup used for biaxial testing. The distal end of the ONS was secured to a fitting, which was connected to a syringe pump. An end-cap with an attached weight was secured to the proximal end of the ONS. The ONS was suspended in a PBS bath and imaged as the luminal pressure was altered by the syringe pump and recorded by the pressure transducer.

## METHODS

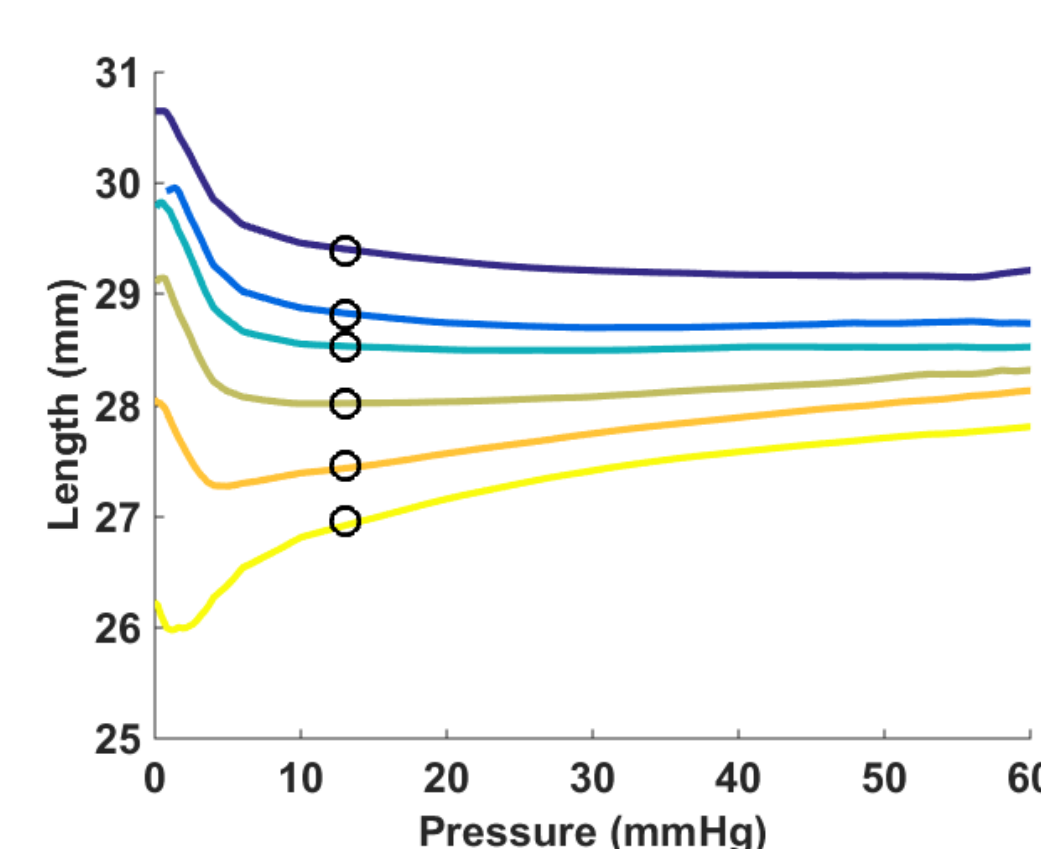
- Mechanical testing system allowed for unconfined lengthening, twisting, and circumferential distension
- ICP was cycled between 0-60 mm Hg
- Outer diameter and length of the ONS were recorded
- Tests were performed under variable axial loads

## RESULTS

### Response of the ONS to Pressure

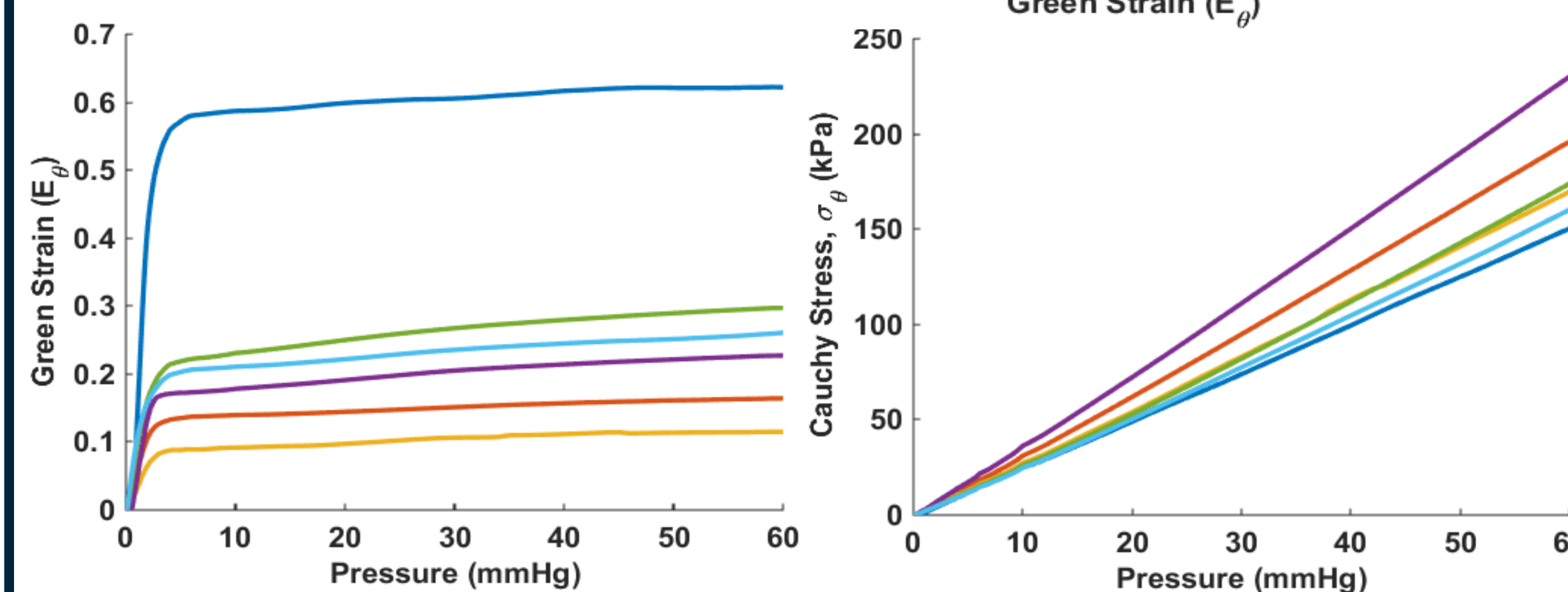
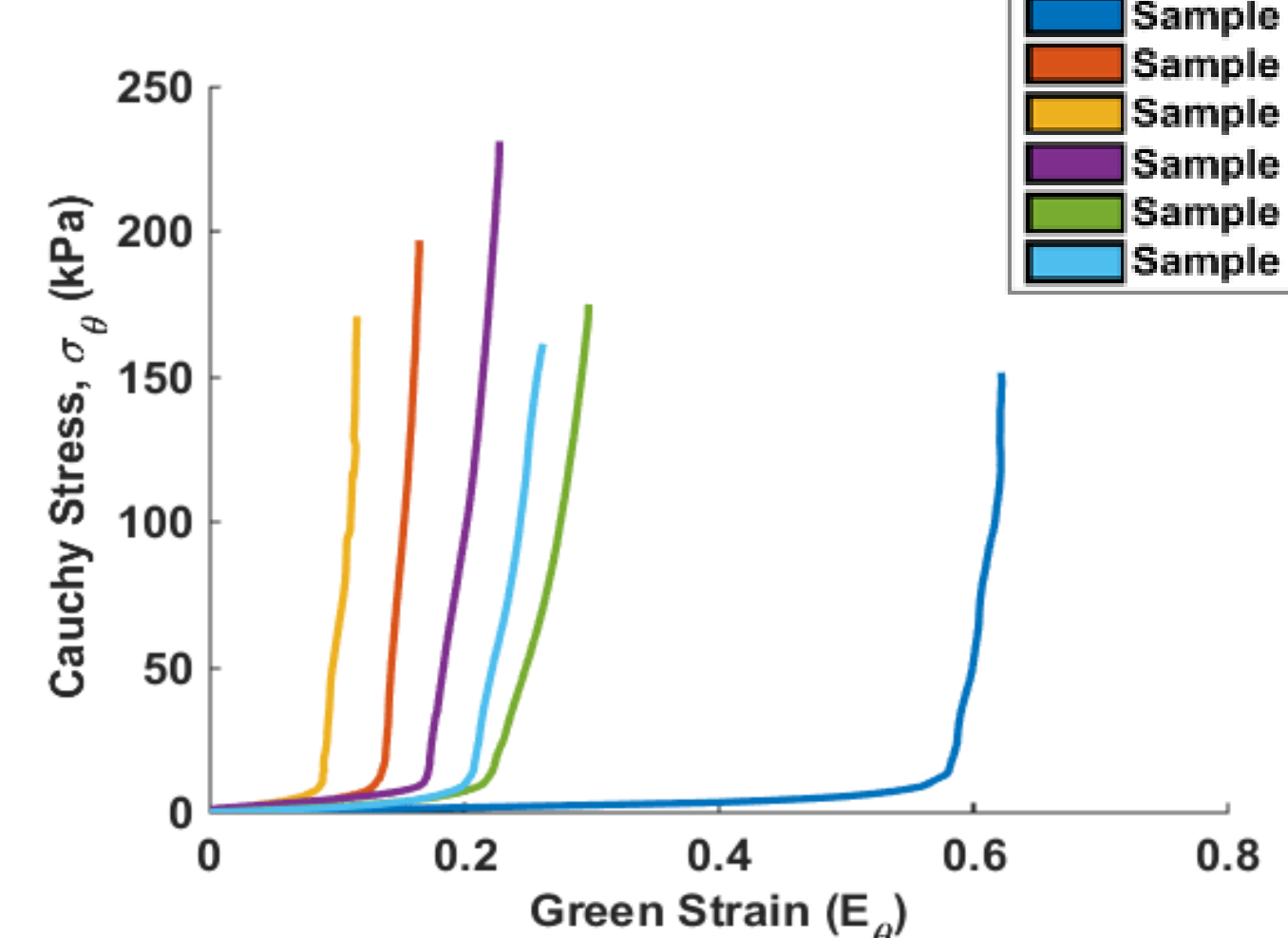


Representative pressure-diameter response of the ONS at different axial loads. Note that the curves cross over at ~11 mmHg (black circle), suggesting that at this pressure the diameter does not change despite variations in axial loading.

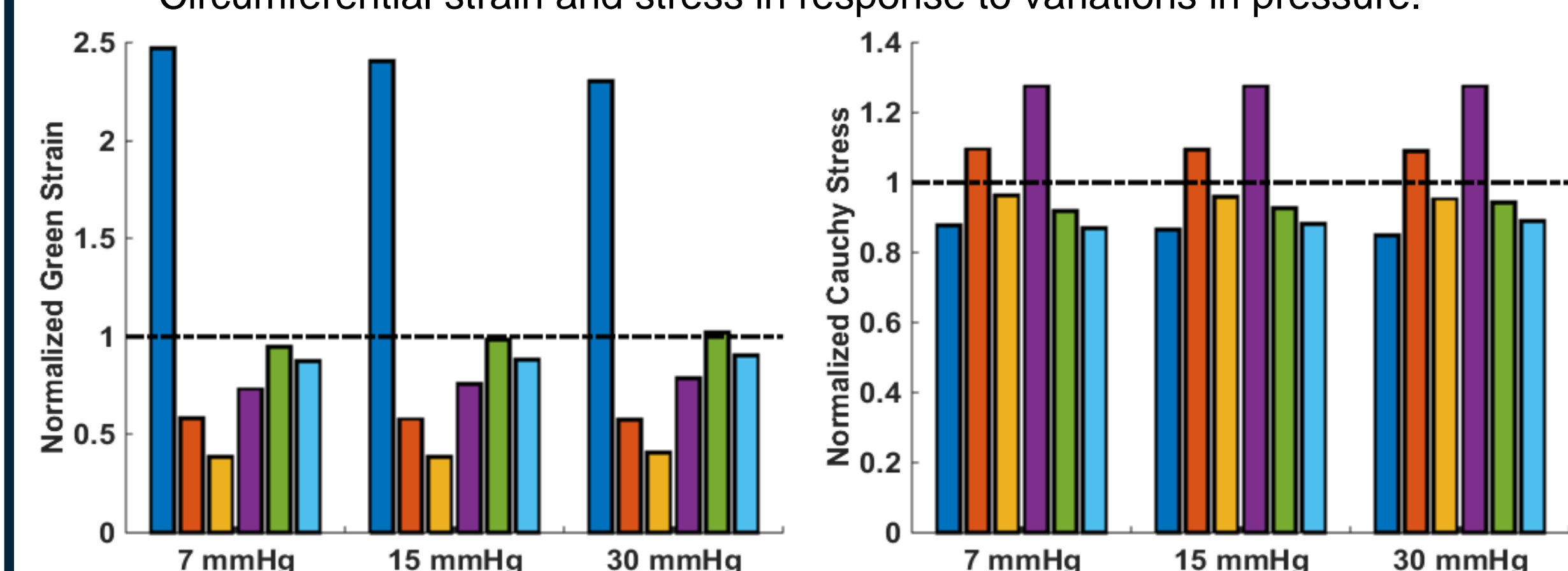


Representative change in length in response to pressure. The length of the ONS adjusts to maintain a constant diameter at ~11 mmHg.

Cauchy stress-Green strain response of 6 porcine ONSs. Note the large sample-to-sample variability in the stress-strain response. These variations were not correlated with any changes in geometrical properties of the ONSs.



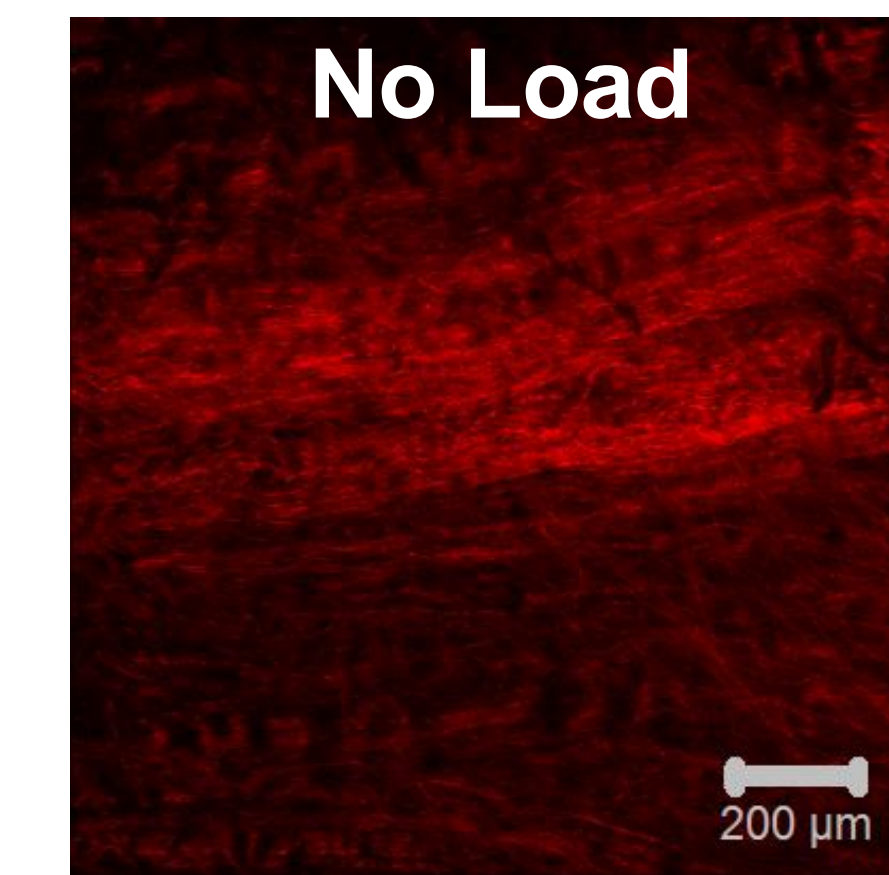
Circumferential strain and stress in response to variations in pressure.



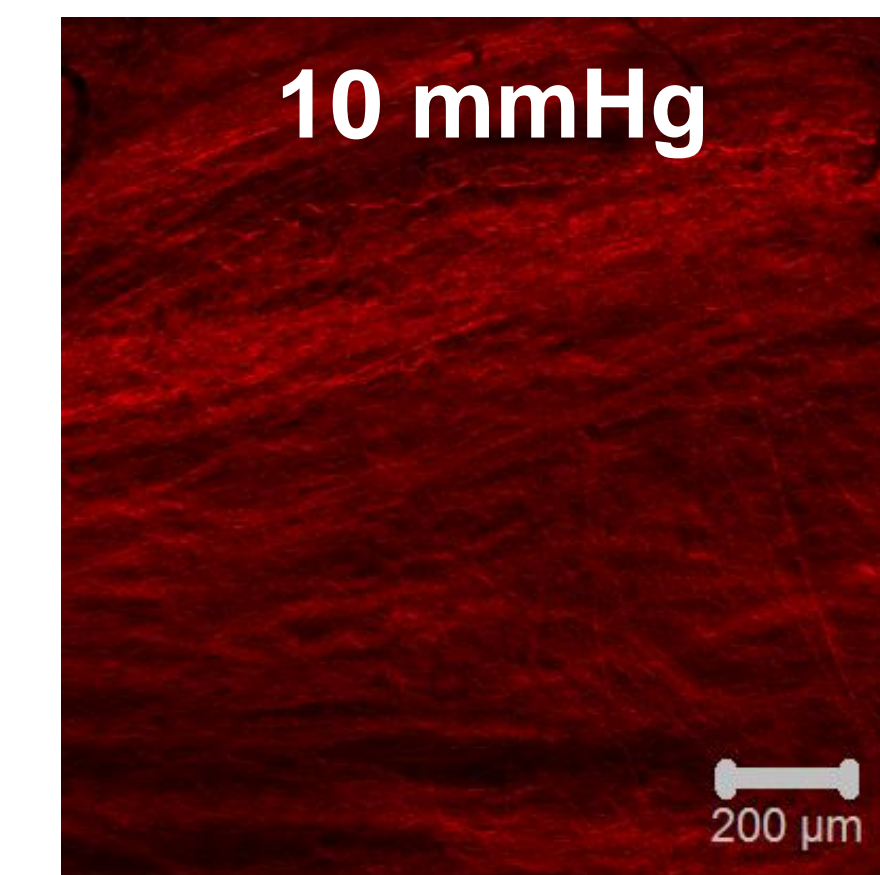
Circumferential strain and stress at 7, 15, and 30 mmHg, normalized to the mean strain and stress over all samples at these pressures. Note the large sample-to-sample variation in the strain, but only modest variation in the stress.

## RESULTS

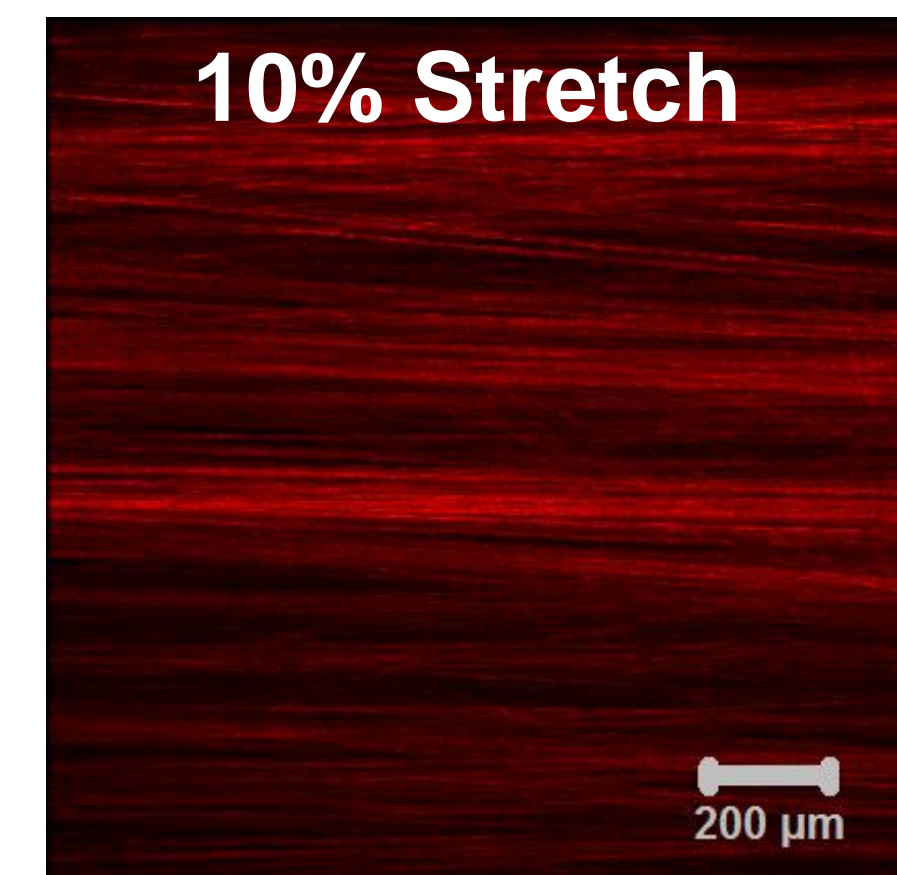
### Axial Alignment of Collagen Fibers During Loading



No Load



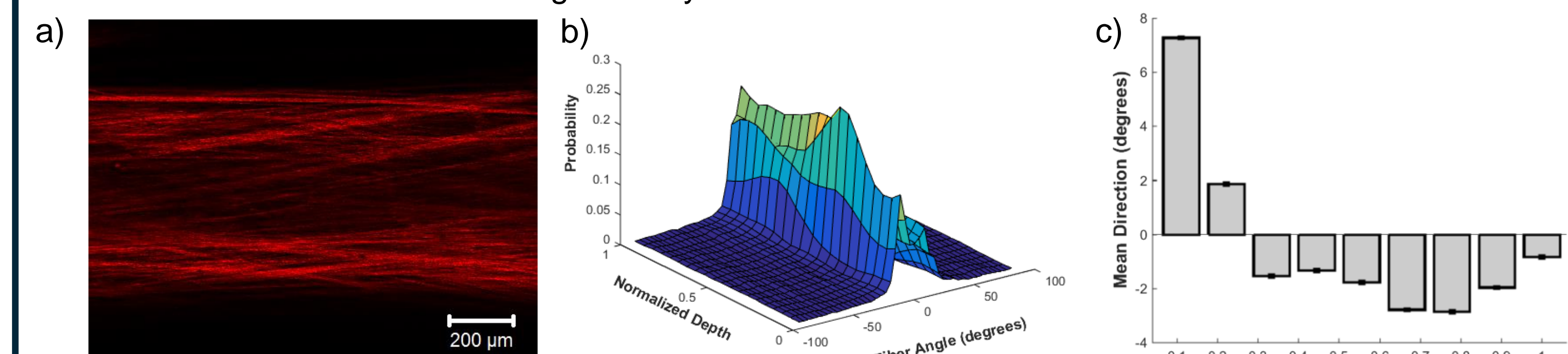
10 mmHg



10% Stretch

Circle  
↑  
Axial

Second harmonic generation microscopy of collagen architecture in the porcine ONS under different loads. Axial stretch appears to affect collagen orientation and microarchitecture significantly more than ICP.



a) Second harmonic generation microscopy of a single, unpressurized porcine ONS at an axial stretch ratio of  $\lambda_z=1.2$ . b) Fiber distributions of the same ONS taken at various locations across the wall. A normalized depth of 0 corresponds to the inner surface and 1 corresponds to the outermost surface. c) Mean fiber alignment angle (mean of the von Mises distribution). Error bars indicate the mean  $\pm$  one standard deviation.

## CONCLUSIONS

- The ONS is a mechanically complex structure
- Crossover point at 11 mmHg of the pressure-diameter curves
  - Diameter remains constant at this pressure regardless of the axial load that is applied
  - Corresponds to in vivo ICP levels for pigs (Kaiser et al. Laboratory animals, 2007)
  - The observed helical and axial orientation of the collagen fibers may explain this behavior
  - Such mechanical behavior would avoid compression of the optic nerve during change in gaze angle
- Despite large variations in strain, the stress remained nearly constant between samples
- Remodeling of the ONS may be targeted at maintaining this homeostatic stress target

Future studies will involve studying the effects of varying ICPs for extended periods of time on the mechanical properties of the ONS. In addition, we will include these observations into current computational models of the optic nerve to help improve their accuracy and enable prediction of possible risk factors of VIIP.

## ACKNOWLEDGEMENTS

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